U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1475

SOIL PRODUCTIVITY

AS AFFECTED BY

CROP ROTATION

THE NATION will have to depend upon the cultivation of the soil for about one-third of its combined wheat, corn, and oats produce; upon crop rotation for another third; and upon the use of manures and commercial fertilizers for the other third.

Crop rotation is nearly as effective as farm manure and complete commercial fertilizers in maintaining and increasing soil productivity, as based on experimental yields of wheat, corn, and oats, taken collectively.

When rotation and the use of fertilizers are practiced together the one practice adds to the benefits of the other.

The relative effectiveness of rotation, as compared with fertilizers, on soils supplied with lime is practically 20 per cent higher than on acid soils.

On soils long under cultivation highest yields are possible only when rotation and the use of fertilizers are practiced together.

In rotation of crops a farmer has at his command, ordinarily without any monetary cost to him, a means whereby he can materially increase the output of his land and reduce acre costs.

A proper rotation is the basis of intensive farming and of profitable land utilization; it provides an effective means for meeting the problem of food production; it permits of farming with livestock; it provides rest for the land, in that leguminous and other renovating crops are alternated with those of an exhausting nature; it permits of clean cultivation and weed control; and it creates other productive-soil conditions.

Crop rotation is the beginning of organized or business farming.

Washington, D. C. Issued May, 1926

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SOIL PRODUCTIVITY AS AFFECTED BY CROP ROTATION

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FOUR ROTATION FACTS

A STUDY of the long-continued soil-fertility experiments of this country and of England, made by the Department of Agriculture,[1] has brought out the following important facts about crop rotation in its relation to soil productivity, as determined by the soil conditions under which these experiments are conducted:

(1) In general, crop rotation has been found to be practically 95 per cent as effective as farm manure and complete commercial fertilizers in maintaining the yields of wheat, corn, and oats, and about 90 per cent as effective as these fertilizers in increasing the yields of these three major crops.

(2) The beneficial effects of crop rotation do not impair the benefits derived from the use of fertilizers; so that when these two farm practices are combined the one practice adds to the benefits of the other.

(3) When compared with the effectiveness of manure and commercial fertilizers, the relative value of crop rotation is practically 20 per cent higher on soils sufficiently supplied with lime than on soils that are acid.

(4) On soils long under cultivation the highest yields are possible only when the use of manure or commercial fertilizers and rotation of crops are conjoined or practiced together.

These facts are shown graphically in Figure 1.

EXPLANATION OF TERMS

In order to make clear the rotation facts on which this bulletin is based, explanation is here given of a few of the terms used.

[1] A Study of the Value of Crop Rotation in Relation to Soil Productivity, United States Department of Agriculture, Bulletin No. 1377.

ROTATION OF CROPS

By crop rotation is meant, in general, the growing of different kinds of crops in recurring succession on the same land. A rotation that is best suited to the conditions of a soil and to the characteristics of the crops grown, and from which a farmer may realize maximum benefits, may be called a proper rotation. In more specific terms, a proper rotation may be defined as a system of cropping in which the right combination of intertilled, small-grain, and grass or legu-

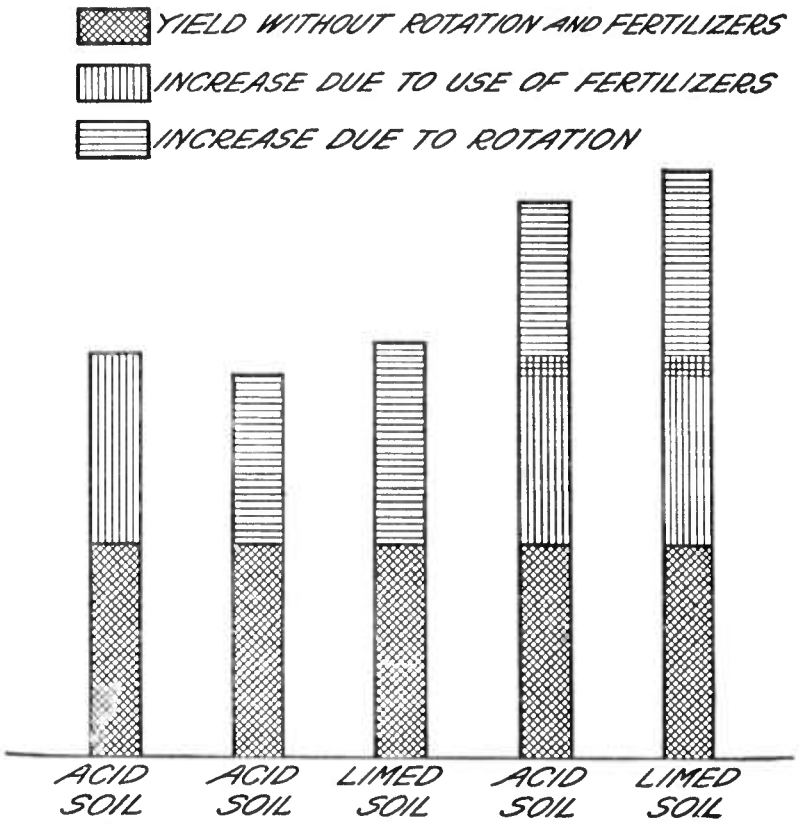

FIG. 1.—Chart showing the importance of crop rotation in relation to soil productivity, as based on the average yields of wheat, corn, and oats obtained in long-continued fertility experiments. The bars represent relative acre yields. The average increase effected when rotation and the use of fertilizers are conjoined does not quite equal the sum of their separate increases, as indicated by the right-angle crosshatching in each of the last two bars

minous crops is grown in the right order and in recurring succession on a given field, or on the same land.

Rotations may also be classed as fixed and flexible. A fixed rotation may be defined as a system of cropping in which the different crops recur at regular intervals and which occupies a fixed number of years. A flexible rotation, on the other hand, may be defined as a cropping system in which intertilled, small-grain, and grass or leguminous crops are grown in the order named, but in which the specific crops may be varied or changed, and in which the number of

years is not fixed. The following cropping plans illustrate fixed and flexible rotations. (See also figs. 2 and 4.)

A. FIXED, FOUR-YEAR ROTATION

First year, corn (one year).	Third year, wheat (one year).
Second year, oats (one year).	Fourth year, clover (one year).

B. FLEXIBLE ROTATION

Potatoes or corn (one year).	Soybeans or a combination of clover, timothy, and redtop (one or two years).
Barley or wheat (one year).	

Because of changed conditions, rotation B may be changed to the following flexible system:

Corn or corn and potatoes (one year).	Corn (one year).
Oats or barley (one or two years).	Wheat or oats (one or two years).
Clover (hay or pasture, one year).	Clover (hay or pasture, one year).
or	Pasture (one year).

The cropping systems on which the foregoing rotation facts are based are all fixed rotations. At Rothamsted, England, it is a four-course system consisting of rutabagas, barley, clover, and wheat; at Columbia, Mo., four different fixed rotations are included in the experiments; at Wooster, Ohio, it is a five-year rotation of corn, oats, wheat, clover, and timothy; and at Urbana, Ill., a three-year system of corn, oats, and clover is used.

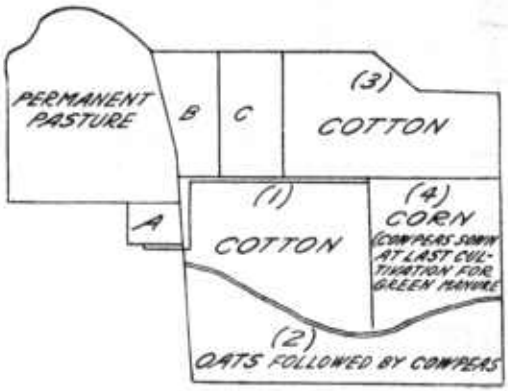

FIG. 2.—A farm layout illustrating a fixed 4-year rotation of cotton, oats, cotton, and corn, occupying the greater part of a southern farm. A, Farm buildings, garden, etc.; B and C, sweet potatoes, peanuts, or other crops

Number of years covered by experiments.—The Rothamsted results which were included in the study of the value of rotation cover a period of 72 years; the Missouri results include a period of 30 years; the Ohio data represented 25 years; and the results selected from the Illinois experiments cover a period of 14 years.

COMPLETE COMMERCIAL FERTILIZER

A complete commercial fertilizer is one which carries all three of the major nutrient elements—nitrogen, phosphorus, and potassium. In the long-time experiments referred to, rotation values were compared with the effects of complete fertilizers, because these fertilizers were found to be more consistently effective in maintaining and increasing soil productivity than those commercial fertilizers in which one or two of the major fertilizing constituents are lacking.

SOIL PRODUCTIVITY

Soil productivity or soil fertility may be defined as the inherent power of a soil for producing good or large yields. The producing

power of a soil, whether high or low, is measured or determined only by the character of plant growth or by crop yields.

PRACTICAL INTERPRETATION OF ROTATION FACTS

It is to be observed that the bottom of each bar in Figure 1 represents the average "yield without rotation and fertilizers." This yield has been determined by the tests in which a crop is grown continuously on the same land without any manure or commercial fertilizer. This part of each bar represents, therefore, the yield credited to cultivation of the soil, which includes the preparation of the seed bed and any subsequent tillage or intertillage to kill weeds or to conserve soil moisture. Thus three farm practices are represented in Figure 1—cultivation of the soil, the use of fertilizers, and rotation of crops.

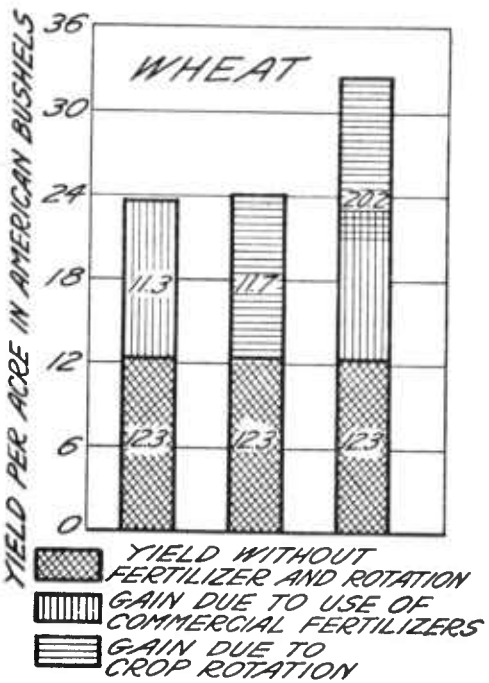

FIG. 3.—Chart illustrating the results obtained with complete commercial fertilizers and rotation on wheat at Rothamsted, England; showing the average yield obtained from cultivation alone, the increase effected by the use of fertilizer or crop rotation when practiced separately, and the increase effected when the use of fertilizer and rotation are conjoined. The increase effected by rotation and the use of fertilizers combined is 2.8 bushels less than the sum of their separate increases, as indicated by the right-angle crosshatching in the third bar

Illustrating the foregoing rotation facts in this manner gives a clearer idea of the comparative and relative values of rotation, and helps to bring out and to emphasize other relations, three in particular: (1) Crop rotation without the use of any manure or commercial fertilizer is nearly as efficient in effecting crop increases as the use of fertilizers without rotation; in other words, the average benefits of rotation are nearly equal to the benefits derived from fertilizers when they are applied to crops grown continuously on the same land; (2) when rotation of crops and the use of fertilizers are conjoined or practiced together, the total increase effected is nearly equal to the sum of their separate increases; (3) from the point of view of soil-management practices, the average total produce per acre of wheat, corn, and oats obtained in these experiments may be divided into three almost equal parts, about one-third being credited to the cultivation of the soil, almost a third to the use of fertilizers and lime, and a third portion to rotation (see the last bar in figs. 1 and 3).

These experimental results throw new light upon the problems of our future food supply and of a permanent national agriculture. It

would seem that we shall have to depend upon the cultivation of the soil for at least a third of our wheat, corn, and oats produce, taken collectively; upon the use of soil-improvement materials, such as manure, commercial fertilizers, lime, and green manure, for another third; and upon rotation of crops for the other third. Just as the alternation of crops has played a large part in the improvement of husbandry in the leading nations of the world, particularly during the last half of the eighteenth century and since, so crop rotation in its improved forms is destined to become one of three outstanding factors in the providing of food for our future millions of population.

AIM OF THIS BULLETIN

The purposes of the discussion which follows are to emphasize the value of crop rotation in farming economy and to stress the principles of rotation in their relation to the maintenance of soil productivity and to soil improvement.

A NATIONAL ROTATION NOT POSSIBLE

According to Government statistics, cotton, corn, wheat, oats, and hay are to be regarded as the five major crops grown in the United States, each occupying more than 30,000,000 acres on American farms.[2] The fact that these five crops occupy 87.5 per cent of the total crop area of the country suggests, in theory, a five-course national rotation. But, practically, it is out of the question to consider any kind of rotation that would be suited to all sections of the United States, because the country, being so large, has such wide differences in climatic and other agricultural conditions. However, a study of the distribution of the important crops grown in the agricultural regions of the United States, within the several States and within smaller areas or districts, will show that flexible rotations are practicable in most sections or localities or on most farms. Possible exceptions are on specialized, one-crop farms and in certain dryland farming sections where, because of scant rainfall, a change from a one-crop system, as from wheat alternating with fallow, is practically impossible or economically hazardous.

ROTATION PRINCIPLES HAVE UNIVERSAL APPLICATION

It is plain that in a bulletin treating of a subject such as this it is not only impracticable but impossible to hinge the discussion on a rotation type, as it is possible in a discussion of a particular breed of livestock or of a variety of corn, to present a standard by type description. But though rotations in different sections, in a given locality, or even on a single farm may differ, because of the manifold circumstances that must be taken into consideration, the principles of crop rotation must be conceded to have general application.

When the principles governing proper rotations are understood by a farmer, he is in a position to think through his cropping problems; and, being guided by principles, he is better able to establish on his fields systems of cropping that will mean higher and more permanent yields produced at lower acre cost.

[2] W. J. Spillman, Distribution of types of farming in the United States, Department of Agriculture Farmers' Bulletin 1289.

FIXED v. FLEXIBLE CROPPING SYSTEMS

Attention has been called to the fact that, in each of the experiments on which the foregoing facts about the value of rotation are based, the experimental plans are rigid or fixed, there being no modification in the rotation and but little or no change in the fertilizers used. In long-continued fertility experiments, fixity of plans is generally accepted as necessary; but, in practical experience, the farmer usually adopts more or less flexible cropping plans, in that he may alter or even change his rotation or rotations, if necessary, or he may vary the fertilizer treatment in order best to meet the soil and crop requirements, or he may lime his soils only when conditions indicate the necessity for liming. In this manner the maintenance of soil productivity may be accomplished most effectively, as may be observed by studying the soil-management methods practiced by leading farmers, particularly those in the older agricultural sections. It is this idea of elasticity in the cropping system that has given rise to the term "flexible rotation," already defined in a preceding paragraph.

It is not possible to know with any degree of certainty what the average relative value of rotation would have been if, in the experiments previously mentioned, the cropping plans had been given sufficient elasticity to provide or create best conditions for all the crops considered. That flexibility or breaking of the rigidity of the experimental plans would have resulted in higher average yields seems quite certain, since the high average yields obtained by leading farmers carry considerable significance.

FACTORS DETERMINING ROTATIONS

In rational farming, factors like soil type, kind of crop, lay of the land, and economic conditions compel variations in the use of soil-improvement materials and in rotations on probably the majority of farms. Because of the lack of uniformity in conditions on individual farms, taking into consideration all farms, there are only a comparatively few farms having conditions favorable to permit of each being divided into a certain number of fields to accommodate a single, fixed rotation. Uniformity of soil, as regards kind or producing power, is the unusual rather than the average condition that prevails. A rotation best suited to a field of low-producing sandy soil is hardly suited to a highly productive silt loam. A hillside field subject to soil washing calls for a different management as regards rotation than a field on a flat area, and so on. It is often easier to vary a rotation to suit the fields than to alter the fields to suit a rotation. (Fig. 4.)

The primary question that confronts a farmer who farms more or less with livestock does not concern rotation so much as it does the acreage of crops necessary to meet his feeding requirements. On the other hand, the truck grower is concerned primarily with the question of crops in relation to market conditions. In either case rotation is a means to an end, and the cropping problem resolves itself into two parts: (1) The growing of the desired crops in a manner, or in different rotations, best suited to the soil and crop conditions; and (2) the dovetailing, as it were, of the different rotations

so as to enable the farmer to realize annually the required acreage of each crop he desires.

Local conditions may arise which will make flexibility of rotations highly desirable, such as insect pests, crop diseases, or weeds. In Tennessee, for example, a simple means recommended for reducing army-worm injury was to change a common fixed rotation of corn, wheat, and meadow to corn and cowpeas for the first year, wheat for the second, and meadow for the third year. In order to

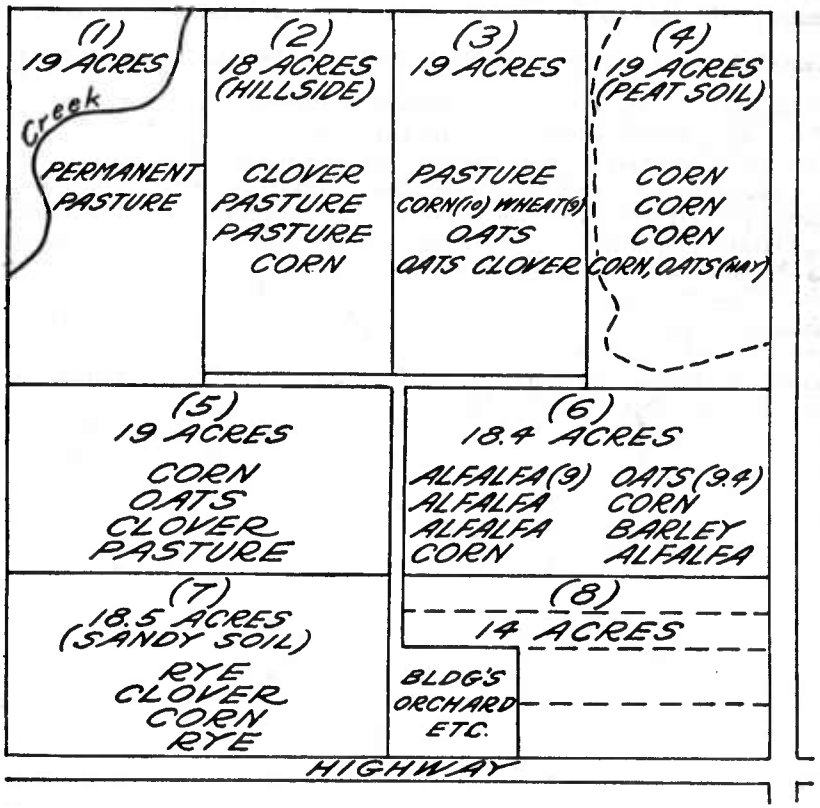

FIG. 4.—Diagram of a 160-acre farm, illustrating soil conditions which necessitate the application of the principle of flexibility in cropping. Field 2 is a hillside, field 4 consists mostly of peat soil (drained), field 7 is sandy soil, field 6 has soil conditions favorable to alfalfa, and field 8 is devoted to a 4-year rotation of clover, cabbage, tomatoes, and barley or wheat. Each year the farmer desires to grow about 38 acres of corn, 32 acres of hay, from 30 to 37 acres of small grains, 18 or 19 acres of pasture in rotation, and 3.5 acres each of cabbage and tomatoes

combat some obnoxious weed a farmer may introduce into the rotation on a certain field an additional intertilled crop.

Changes in economic or market conditions may compel rotation changes. England affords a good example of the effect of changed economic conditions on a cropping system.[3] For more than a century the celebrated Norfolk four-course rotation of roots (turnips

[3] Rew and Russell. Possibilities of British Agriculture, in Rothamsted Memoirs, Vol. XI, 1920–22.

or rutabagas), barley, clover, and wheat was regarded as the standard rotation in British agriculture; but now it is being found (by the Northumbrian farmers in particular) that better results can be obtained when, in the Norfolk plan, the hay crop is left two years instead of one, thus making it a five-course rotation.

In planning rotations the farmer should be mindful of the possibility that changes in rotation may become desirable or necessary. Confronted with such possibilities he may come to realize that, under like conditions, a cropping system which will permit of easy alteration is preferable to one that does not possess this quality of elasticity.

FLEXIBILITY IN CROPPING, A PRINCIPLE IN FARMING ECONOMY

The idea of elasticity in the cropping system is not new. In fact, it long ago passed beyond the experimental stage; nor does it now require any demonstration for proof, for so long has it been recognized as a factor in successful farming that it may be stated as a fundamental principle in farming economy. In all probability the farmers of Flanders applied this principle in their husbandry as early as the Middle Ages (476–1300 A. D.), if not before or during the time of the Roman Empire. About 1600 A. D., English writers on husbandry referred to certain cropping schemes of the Flemish farmers, such as change of crops and adaptation of crops to soil conditions, as having been practiced by them from times immemorial. And, in 1645, Sir Richard Weston,[4] on discovering the secrets that made possible the highly successful husbandry of the Flemings, gave such a definite expression of this principle of flexibility or of elasticity in cropping that his statement of it needs no modification to make it applicable as a guiding principle in successful soil management even in our modern and scientific age. While yet in Flanders, Sir Richard recorded the following words in his "Legacy" to his son:

> It is a certain thing, that the chiefest and fundamentallest point in Husbandrie, is, To understand the nature and condition of the Land that one would Till; and to sow it with such Seed as it will produce, either Naturally, or by Art, that which may turn to a Man's greatest profit and advantage.

ROTATION v. FERTILIZERS IN LAND UTILIZATION

In the utilization of arable lands, economists recognize three stages of development. The first stage is a period in which virgin, productive soils are usually subjected to exhaustive cropping, and in which little or no thought is given to proper cultivation or to returning anything to the land with a view to prolonging its productivity. Very often this stage is characterized by the growing of one major crop almost continuously on the same land, such as tobacco during the early colonial days, particularly in Maryland and Virginia, and later on, in other sections, wheat or corn. During this first period the value of manure is hardly appreciated, crop rotation is rarely practiced, and, as one observer has stated it with particular reference to colonial farming, new land is constantly brought into cultivation as soon as that which is already under the plow refuses to produce anything that is worth harvesting.

[4] Sir Richard Weston, The husbandrie of Brabant and Flanders, in Hartlibs's Husbandrie, 1654, p. 5.

The second stage is a period in which the farmer realizes that, if he is to succeed in growing any crops at all that would give him sufficient encouragement for his labors, he would have to cultivate his land more carefully, modify his cropping system and utilize any farm manure produced for the good of the land, all with a view to preserving, in a manner, the producing qualities of his soils. This period may be called the extensive stage.

The third stage is a period in which the farmer gives much thought to cultivation and to drainage, if necessary, to rotation of crops, and to the use of soil-improvement materials. This is the intensive stage, which ultimately results in a higher yield per acre, but a smaller yield per man. With the average farmer, the sign of his approach to the third stage is the increased attention he gives to those soil-management practices which enable him to produce high yields at the lowest possible cost per acre.

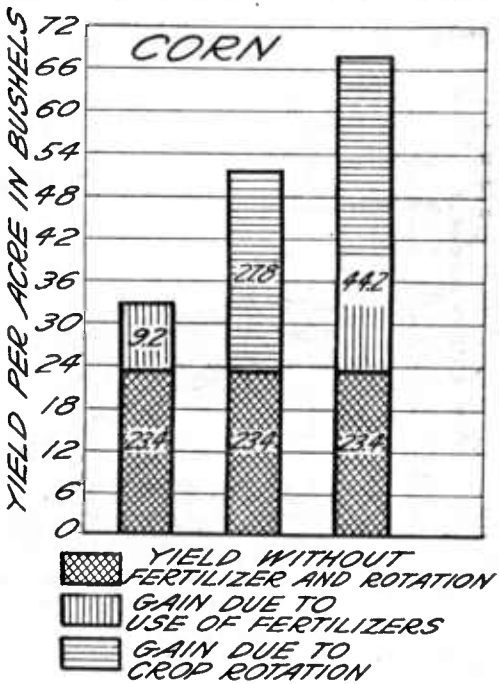

FIG. 5.—Chart visualizing the experimental results obtained in growing corn on fertile prairie soil at Urbana, Ill., showing the average yield obtained from cultivation alone, the increase effected by the use of fertilizer or crop rotation when practiced separately, and the increase obtained when the use of fertilizer and rotation are conjoined

ROTATION AS GOOD AS FERTILIZER

In the light of the study that has been made of the value of crop rotation, it may well be assumed that on naturally productive soils a proper rotation may for many years prove more effective in maintaining yields than farm manure or single, mixed, or even complete commercial fertilizers. In time, however, the manure or commercial fertilizers may give more and more positive results until they approach the effectiveness of rotation, as the experiments with corn at Urbana, Ill., seem to show.

In the experiments at Urbana the soil treatment consists in the use of pulverized limestone, farm manure, and phosphate fertilizers (bone meal and rock phosphate); and the rotation consists of corn, oats, and clover. (See fig. 5.)

Three important points are brought out in the chart in Figure 5: (1) The average yield of corn obtained without fertilizers and rotation on this particular prairie soil in Illinois is 23.4 bushels per acre (equivalent in bushels of shelled corn); (2) the gain effected by rotation alone is practically three times that obtained from the use of fertilizers and lime; and (3) the total increase effected by con-

joining rotation and the use of fertilizers is 7.2 bushels greater than the sum of their separate increases.

It is a well-known fact that, when an arable soil is well supplied with organic matter, nitrogen, and the necessary mineral elements, it shows but little or no response to fertilizer treatments. On the other hand, a particular crop may be grown successfully on the same land only when it is introduced into a rotation. This is particularly true in case the crop is attacked by certain insect pests or crop diseases, in which case the change of crops aids in the control of such insects or diseases or prevents their development.

ROTATION AND USE OF FERTILIZERS COMPANION PRACTICES IN PERMANENT AGRICULTURE

It is to be observed that cultivation of the soil in some manner is a necessary farm practice in all the stages of development in land util-

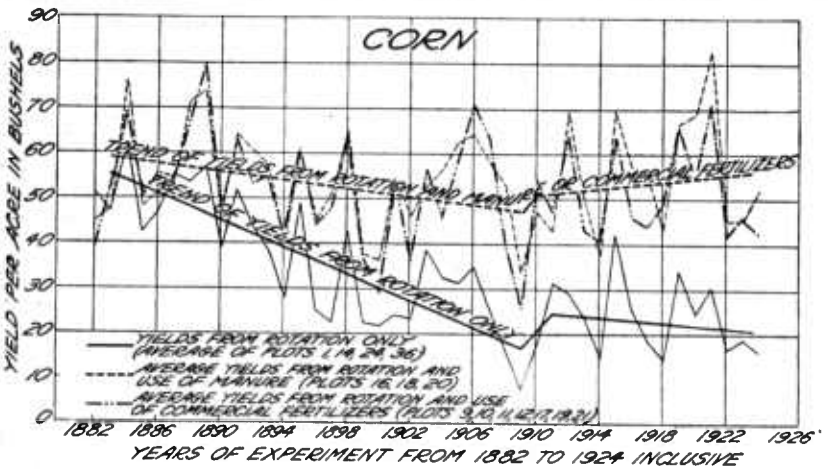

FIG. 6.—Diagram illustrating the fact that, in permanent soil productivity, highest yields are possible only when rotation and the use of fertilizers are practiced together, as shown by the yields of corn obtained in 43 years of experimental work at State College, Pa. Note that, under rotation alone, the producing power of the soil has gradually declined, as indicated by the trend of the average yields obtained from rotation; and that, under the conjoint effects of rotation and the use of manure or commercial fertilizers, soil productivity has not suffered decline as in case of rotation alone. (From published and unpublished data of the Pennsylvania Agricultural Experiment Station)

ization, and that as virgin and arable lands are kept longer and longer under cultivation, crop rotation and the use of fertilizers become companion practices to which a farmer must give more and more attention if he desires to retain ownership of his farm lands. History shows that sooner or later one-crop farming or any form of continuous exhaustive cropping brings the best of virgin soils to a point where the use of manure or some form of commercial fertilizer, or a combination of both, becomes necessary in order to make them produce profitable yields, and also to a point where the highest yields and permanent productivity can not be attained without conjoining rotation of crops and the use of fertilizers with the oldest of all farm practices, the cultivation of the soil. The results of the long-continued fertility tests obtained in this country and in Europe prove this point experimentally. (Fig. 6.)

ROTATION NOT AN ITEM OF EXPENSE IN COST ACCOUNTING

In farm cost accounting, cultivation of the soil is represented in the cost columns by different expense items, such as plowing, harrowing, and cultivation; so that the tillage necessary in the preparation of the seed bed and any subsequent cultivation or intertillage are more or less expensive farm operations. Fertilizers also appear as an item of expense, including initial cost of the materials, and other costs such as interest charges and costs involved in getting the fertilizers applied. Many expenditures on one crop help to benefit succeeding crops. The cultivation of corn leaves the land weed free for the small-grain crop following, fertilizer applied to wheat helps the growth of the grass as well, while the roots and organic matter left by the grass crop, plus accumulated nitrogen if a legume is used, leave material for the corn to feed on. To be entirely adequate, any system of cost accounts should show credits to each crop for its contribution to the next one. Unfortunately these contributions of one crop to another are of such a character that they can not be measured, hence can not be shown in cost accounts, but they are very real for all that.

Rotation of crops, on the other hand, does not appear as an item of expense in any farm cost-accounting system. This means that whatever time or energy a farmer expends in planning a rotation, that is, in determining a sequence of crops which will enable each crop to derive the maximum benefit from preceding crops and give the greatest benefit to subsequent crops, and in getting the rotation established on his farm, is counted as an expression of his managerial ability, for which he receives reward in the form of managerial income, if through good management he succeeds in realizing net profits. Thus in rotation of crops a farmer has at his command, ordinarily without any monetary cost to him, a means whereby he can materially increase the output of his land and reduce acre costs. It is a farm practice which may prove equally as effective or even more so than the use of manure or commercial fertilizers in maintaining and increasing the productivity of his soils. This important fact regarding the value of rotation in relation to production costs is worthy of the serious consideration of every American farmer.

INTERACTION OF ROTATION, CULTIVATION, AND SOIL FERTILIZATION

The importance of cultivation, rotation, and of the use of fertilizers in permanent soil productivity must be recognized, if the results of long-continued fertility experiments carry any significance. It has been shown that each of these farm practices has a separate value in relation to productivity. It is logical to believe that cultivation aids both rotation and fertilization, that rotation aids in rendering fertilizers more effective, and that fertilizers increase the value of rotation. That rotation and the use of fertilizers, when practiced together, may interact to the extent that their conjoint effects, as measured in terms of crop increases, may be greater than the sum of their separate effects is clearly shown in the experiments with corn at Urbana, Ill. (see fig. 5), and in the experiments with commercial fertilizer on both wheat and corn at Wooster, Ohio (see figs. 7 and 8).

INTERRELATION OF ROTATION, CULTIVATION, AND FERTILIZATION IN SOIL IMPROVEMENT AND PERMANENT PRODUCTIVITY

In a previous paragraph reference is made to cultivation of the soil, rotation of crops, and fertilization as the outstanding farm practices on which a permanent national agriculture must rest. The experimental results from which this conclusion has been drawn seem to show also that these three farm practices will have almost equal values when the total produce of wheat, corn, and oats, taken collectively, is considered.

Assuming a one-crop system on a given farm, in a community, or for the whole country, the average relative yield of corn, wheat, and oats may be just about doubled by introducing rotation, and if the land has been long under cultivation the further introduction of the use of necessary fertilizers may give an additional increase about equal to that obtained by the introduction of rotation.

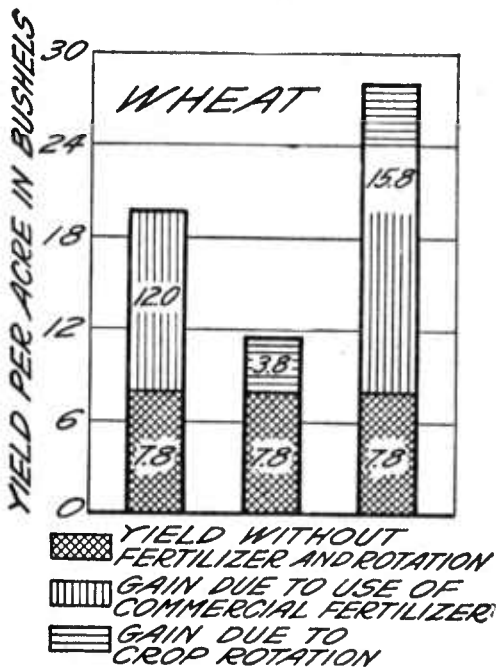

FIG. 7.—Chart showing the results obtained with commercial fertilizer and rotation on wheat at Wooster, Ohio, in which the total increase effected by conjoining rotation and the use of fertilizers is greater than the sum of their separate increases

If conditions were such as to make possible so simple a productivity program, the food problem of the Nation would not prove a serious one for many years to come. The actual conditions, however, call for an entirely different interpretation or application of the facts visualized in Figure 1.

Cultivation of the soil is generally practiced in some manner. Rotation of some sort is practiced by most farmers, even though it may consist in merely a change in crops without any definite plan or any degree of regularity. Farm manure is usually disposed of for the good of the land, and commercial fertilizers are coming more and more into use, either specially in single or incomplete forms to correct certain soil deficiencies or to meet the requirements of special crops, or generally in mixed or complete forms.

Taking into consideration the whole country or any particular section of it, the only way in which cultivation may operate as a factor in maintaining yields or in which it may become effective in increasing soil productivity is by giving attention to or by improving tillage methods or practices. Results along improvement lines can be realized only to the extent that each farmer masters the principles of tillage and studies his soils, crops, and machinery so that

he may be able to make the proper application of the tillage principles to the conditions on his farm through the means at his command.

Farm manure and commercial fertilizers seem to be regarded as possessing the greatest possibilities with reference to maintaining soil productivity and in effecting increases in crop yields. (Figs. 9 and 10.) Judging from the experiences of farmers who have used such materials as dung, seaweed ashes, wood ashes, street refuse, and certain kinds of marl during pre-Roman and Roman times, and from the profound effects that manufactured or commercial fertilizers have had, since 1840, on the agriculture of the leading nations of the world, the basis for the recognition of large possibilities in the use of manure and commercial fertilizers is well grounded.

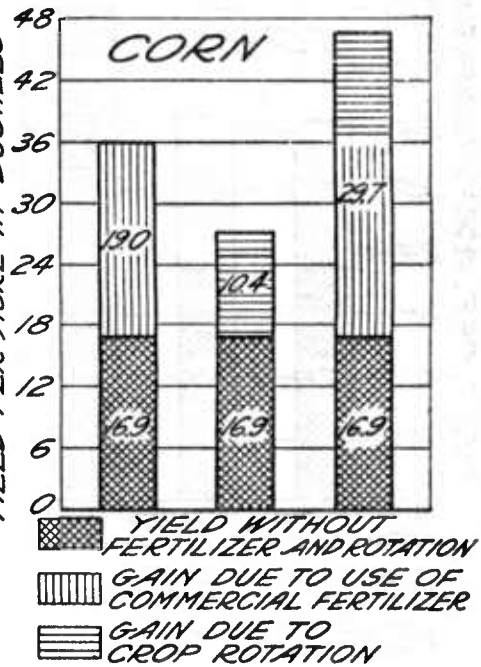

FIG. 8.—Chart showing the results obtained with commercial fertilizers and rotation on corn at Wooster, Ohio, in which the total increase effected by conjoining rotation and the use of fertilizers is somewhat greater than the sum of their separate increases

As regards rotation, its full benefits very probably can not be realized by adhering to fixed rotations, but rather by applying the principle of flexibility in the cropping system. Just as it is possible for a farmer to increase the effectiveness of cultivation and of the use of fertilizers, so it is possible for him to increase the efficiency of rotations as well, by giving more attention to systematic alternation of crops, particularly to proper rotations. (See definition, p. 2.) Furthermore, by means of rotation the farmer is afforded opportunities to improve his soils in ways that do not necessarily depend upon the use of manure or commercial fertilizers, ways which, at the same time, will create soil conditions that may increase the effectiveness of applied fertilizers.

In order that a farmer may accomplish the most by his efforts, either alone or in cooperation with his county agent or State college of agriculture, it is essential that he understand the principles which govern a proper rotation and be guided thereby.

PRINCIPLES OF PROPER ROTATION

There are three principles which govern a proper rotation. The first one concerns soil conditions in general, as affecting soil productivity; the second has to do with the interactive effects of the characteristics of any particular soil on crop yields; and the third con-

cerns the effects of crops on those which follow. These principles may be stated, respectively, as follows:

(1) Soil conditions most favorable to productivity can best be maintained on arable lands when intertilled, small-grain, and grass or leguminous crops are grown in the order named, and in recurring succession on a given area of land.

(2) The conditions or characteristics of a particular soil determine in a large measure what crops are best adapted to that soil.

(3) The growing of one kind of crop affects to a greater or less degree the growth of another crop which follows.

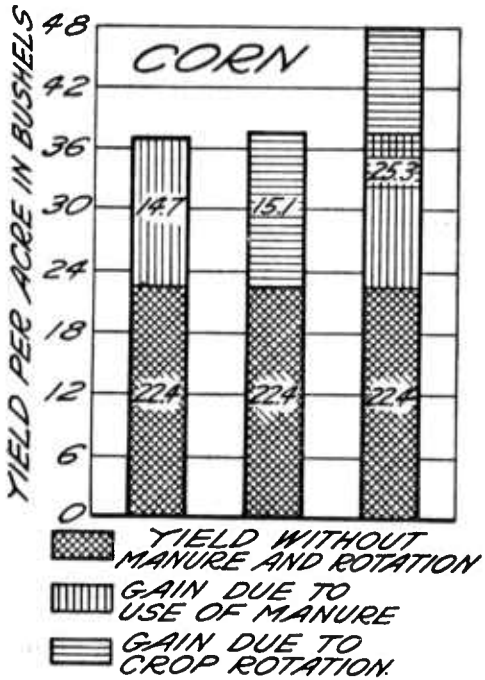

FIG. 9.—Chart illustrating the results obtained with manure and rotation on corn at Columbia, Mo., showing the average yield obtained from cultivation alone, the increase effected by the use of manure or rotation when practiced separately, and the increase effected when the use of manure is added to rotation. Note that in this experiment the gain of 25.3 bushels, as is shown in the third bar, is not fully additive, being less by 4.5 bushels than the sum of the separate gains obtained from the use of manure and rotation

These principles may be transposed into rules of action, as follows: (1) Maintain those soil conditions essential to productivity that are made possible only by alternation of crops; (2) grow those crops which are best adapted to the characteristics of any particular soil; and (3) grow crops in the order that each may have a favorable effect on the one which follows.

ESTABLISHING PRODUCTIVE-SOIL CONDITIONS BY ALTERNATION OF CROPS

The starting point in establishing proper rotations, in harmony with the first of the principles named above, is to grow an intertilled crop, a small-grain crop, and a grass or leguminous crop in the order as named. The selection of these three classes of crops and the order of their cropping have grown out of the practical experiences of farmers of all ages, as indicated by records which cover a period of more than 3,000 years. Because of the fact that the experiences out of which has evolved this practice of proper cropping are deeply rooted in human history, it may prove profitable, in order that the importance of this system of cropping may be fully appreciated to-day, to recount briefly four stages in its development.

"Thou shalt let it rest."—When early peoples adopted sedentary habits, cereals became their chief sources of food. In those primitive times it was natural that these crops should be grown almost continuously on the same fields so long as the land would yield remunerative crops. These early peoples soon learned that continued exhaustive

cropping resulted in lower and lower yields or crop failure and that resting the land renewed its producing power. This knowledge gave rise to the custom of abandoning the land, at more or less regular intervals, to the natural growth of rough and weedy herbage, which offered scanty food for domestic animals. The oldest record of such a practice is to be found in the Mosaic laws, which were given to the Israelites for their government on entering the promised land (about 1400 B. C.). In Exodus xxiii, 10 and 11, we find this command:

> And six years thou shalt sow thy land, and shalt gather in the fruits thereof: But the seventh year thou shalt let it rest and lie still; that the poor of thy people may eat; and what they leave the beasts of the field shall eat. In like manner thou shalt deal with thy vineyard, and thy oliveyard.

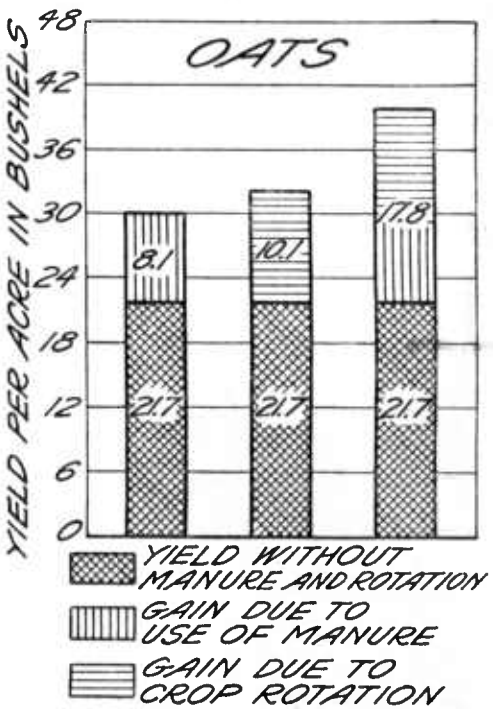

FIG. 10.—Diagram illustrating the results obtained with manure and rotation on oats at Wooster, Ohio, showing the average yield obtained from cultivation alone, the increase effected by the use of manure or rotation when practiced separately, and the increase effected when the use of manure and rotation are practiced together. Note that the total increase of 17.8 bushels shown in the third bar is just about equal to the sum of the increases from manure and rotation

The second or bare-fallow stage.—During the time of the Roman Empire (29 B. C. to 476 A. D.) and in Saxon times (second to eighth century) we meet with the practice of fallowing, which originated from the ancient state of the common field. During this time the village had the control of the land, and husbandry assumed a three-field system, consisting of a winter grain like wheat followed by a spring grain like barley, which in turn was followed by "dead" fallow. This system had two great advantages over the "resting" or "repose" husbandry of pre-Roman days. It enabled the husbandman better to meet the great problem of weeds, and it enabled the farmer, for a time at least, to produce more food per unit of land. This famous triennial cropping scheme of the Romans survived the Dark Ages (476–1300 A. D.) and was reestablished in Europe during the Renaissance; it persisted in England during the eighteenth century in spite of thousands of inclosure acts; it was carried to the New World by the early settlers, and it still lingers even to this day in parts of Europe and the United States.

Third stage, the introduction of clover.—Improvement upon the fallow or repose system of husbandry, attainable by alternating leguminous crops with the cereals, was distinctly recognized by the

Romans more than 2,000 years ago; but this improvement did not make much progress in the field, owing, no doubt, to the rigid adherence to the Roman three-field system. Nevertheless there was one district in western Europe, the light-soil area of Flanders, where the Roman three-field husbandry left no trace. The Flemish farmers had evidently abolished the fallow at a very early date, and from times immemorial had been growing clover and other legumes in rotation with crops like hemp, turnips, and small grains. Here a density of population early demanded not only a more intensive utilization of the land to meet the food problem, but a system of soil management that would permit of the keeping of more livestock and that would establish permanency of soil productivity. (Fig. 11.)

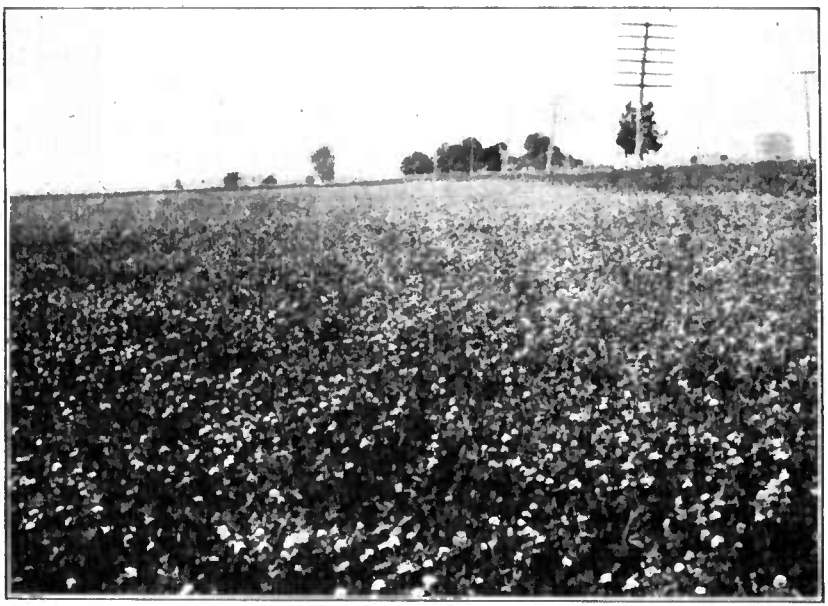

FIG. 11.—Resting the land on good clover. Grass and particularly legumes are the renovating crops in a rotation. The introduction of clover into the rotation was a big step in the improvement of husbandry, and the growth of good grass or legumes is the best evidence of soil productivity

In writing about the clover in Flanders, as he had observed it in 1675, John Worlidge,[5] of England, said of it:

> This Grass hath born the name and is estimated the most principal of Grass, both for the great Improvement it brings by its prodigious Burthen, and by the excellencie of the Grass or Hay for Food for Cattle. * * * It hath also this Property, that after the growing of the Clover-grass * * * it will so frame the Earth, that it will be very fit for Corn again.

From the clover-growing experiences of the Flemish farmers had sprung the following two proverbial sayings, both of which carry ideas worthy of the consideration of the farmers, even in the best-cultivated areas of our country.

> No forage, no cattle; without cattle, no manure; and without manure, no crop.
>
> Without clover no man in Flanders would presume to call himself a farmer.

[5] John Worlidge, System of Husbandry, England, 1675.

So successful were the Flemish farmers, that as early as during 1600 and a part of the century following, Flanders had become the school of a new husbandry in Europe.

Fourth stage, the introduction of intertillage.—In Flanders, and also in other parts of Europe, all seeds sown in the field were broadcast; so that when the Flemish rotation-with-clover husbandry was attempted in England, for instance, it came into conflict with the strongly intrenched grain-grain-fallow system, and above all, with probably the greatest weed problem in the history of English agriculture. Although the art of hoeing in between rows of plants grown in the garden and in the vineyard had been practiced from the earliest times by the Roman farmers, it had not been carried into the field. Nobody seemed to have thought of the idea of applying garden tillage to the crops grown in the field as a means of meeting the weed problem, which would become the more acute on the abolition of the bare fallow, until Jethro Tull (during the early years of the eighteenth century) introduced into English husbandry, particularly on his own farm, the idea of planting crops in rows to permit of their being intertilled. Because of the fact that turnips was the principal intertilled crop in this new cropping scheme, it was commonly called turnip, horse-hoeing or drill husbandry.

For years Tull's ideas were regarded by nearly all English farmers as speculative innovations, and hence they did not make very much of a general impression upon the agriculture of England until near the close of the eighteenth century, when the famous Norfolk rotation of turnips, barley, clover, and wheat, originally introduced into the county of the same name by Lord Townshend in 1730, became firmly established in English agriculture. Then it was that England, instead of Flanders, became the school of agriculture in western Europe.

The keystone principle of rotation.—The introduction of intertillage into the field gave rise to one of the greatest improvements in agriculture. Its introduction as an improvement over the Flemish husbandry completed the development of a system of cropping which gives full expression of the first principle governing proper rotations: Soil conditions most favorable to productivity can best be maintained on arable lands when intertilled, small-grain, and grass or leguminous crops are grown in the order named, and in recurring succession on a given area of land. When it is remembered that it required more than 33 centuries of farming experience to bring this principle to its full recognition, we can begin to appreciate its keystone importance in the solution of many of the agricultural problems brought into existence largely because of the increasing demands of human society.

The application of this first principle is (1) the basis of intensive farming and of profitable land utilization, (2) it provides an effective means for meeting the problem of food production, (3) it permits of farming with livestock, (4) it provides rest for the land in that leguminous and other replenishing crops are alternated with those of an exhausting nature, (5) it permits of clean cultivation and weed control, and (6) it creates other productive-soil conditions.

General applicability of the first principle.—Much can be written describing the different rotations that are possible in the various sections of the United States, as based on the basic principle of

proper rotation which concerns the alternation of intertilled and grass or leguminous crops with small grains. Representatives of these three classes of crops are grown in practically every section of the country, so that this principle may be applied generally. In some sections, as in New England, hay and pasture must necessarily occupy most of the years of the rotation; in other sections, as on the rich prairies of the Corn Belt, two and possibly three crops of corn may be grown in succession on many farms, with clover and small grain; and in the South it would seem that cotton, corn, and legumes will constitute the major crops of the rotations, especially in the southern portion of the Cotton Belt.

Study of soil conditions and characteristics in their relation to crop adaptation.—In the agricultural writings of the ancients, particularly the Romans, we find reference to a very old way of how they used to judge of the productive qualities of virgin lands. They noted the kinds of trees, and the character of their growth, large trees of certain kinds usually indicating a high degree of productivity. This method of judging virgin soils was adhered to for many centuries, and it was generally used during the pioneer days of the settlement of America. On the other hand, lands in humid regions that did not support tree growth were considered unfit for farming. This manner of judging soils may be regarded as an early recognition of the second principle governing proper rotations: The conditions or characteristics of a particular soil determine in a large measure what plants or crops are best adapted to that soil.

The success of the early Flemish farmers was due, in part, to their practical application of this principle. Sir Richard Weston, on visiting Flanders as early as 1645, was thoroughly convinced of the idea that successful husbandry depended largely upon the knowledge a farmer had of the conditions or characteristics of his soils, and upon the extent to which he considered these conditions or characteristics when making the choice of crops he desired to grow. (See quotation on p. 8.) It is the recognition of this principle that has given rise to such terms as "wheat soils," "corn soils," "potato soils," and "tobacco soils"; and to such practical recommendations as the growing of rye on sandy lands, of cowpeas or soy beans instead of alfalfa on soils of medium acidity, of timothy, redtop, and other grasses on heavy soils, and of alfalfa, sweet clover, and red clover on soils sufficiently supplied with lime and other essential constituents.

Because of the interrelationship of soil and crop characteristics, a rotation best suited to a sandy soil may prove a poor one for a heavy clay, and a rotation that proves most profitable on a deep black loam may be a losing proposition on a well-drained peat. On one portion of his land, because of favorable soil characteristics, a farmer may succeed with a rotation containing alfalfa, whereas on another part of the same farm the same rotation may fail because of some unfavorable soil characteristic.

Growing crops in the order that each may affect favorably the one which follows.—The growing of an intertilled crop, a small-grain, and a grass or leguminous crop, in the order named, has come to be recognized as the correct order for these three classes of crops, this practice having been proved by the leading farmers, especially of Europe and America, during the last 200 years. It is well known

that the effects of one crop on the other are beneficial when they are grown in the order indicated; but there are some crops which do not affect favorably certain crops which follow them, as is shown, for example, by the experiments at the Rhode Island Agricultural Experiment Station.[6] Pot tests have shown that onions, buckwheat, and alsike clover grown on soil previously occupied by other crops for two or three successive years varied widely in their yields and that the differences in yields did not seem to have been due to the removal of different quantities of nutrient elements by the preceding crops. Field tests with millet, buckwheat, barley, oats, wheat, and rye have given similar results. In commenting on these results the experimenters said:

> The soil acidity was affected differently by the several crops and, generally, the best yields of the onion, a plant which is sensitive to conditions accompanying acidity, followed the crop giving rise to the least acidity. These indications assume added importance because of the observed fact that the effects of the crops on those which follow were much less divergent if the soil acidity was reduced by liming.

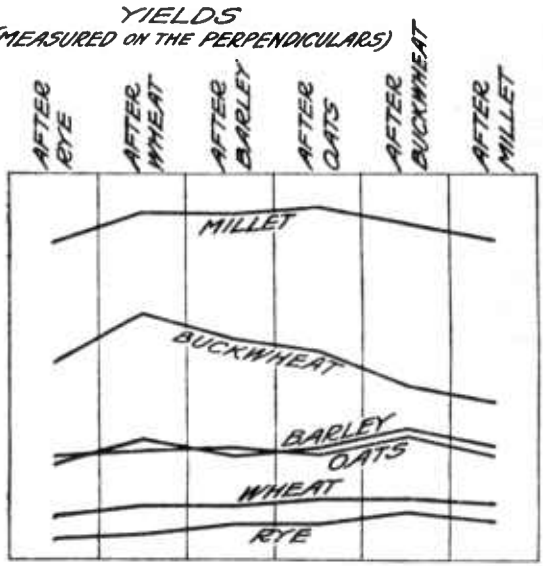

FIG. 12.—Diagram based on relative yields, showing how crops affect the yields of crops which immediately follow. In 1920 these six crops were grown on as many strips running in one direction. In 1921 the same crops were grown in the same field, but in strips crossing the 1920 strips at right angles. It is to be noted that, in this particular experiment, buckwheat gave the highest yield when it followed wheat, and the lowest yield when it followed millet. The yields of barley were best when it was grown after buckwheat and wheat. Oats yielded the poorest after rye, oats, and millet. The yield of rye was best after buckwheat; and the yields of wheat were best when grown after oats and buckwheat

Figure 12, taken from Bulletin 190 of the Rhode Island Agricultural Experiment Station, illustrates, relatively, how yields are affected by preceding crops.

Further work at the Rhode Island station has shown that the yields of corn and oats following corn are better than the yields following mangels.

Other experiment station workers have recognized this third principle of rotation, in its relation to particular crops and under different conditions. For example, at the North Dakota experiment station it has been found that good yields of wheat are obtained after corn, potatoes, oats, rye, barley, flax, and peas; and that the yields are poor after German millet.

The Kansas experiment station has reported that, under irrigation, sugar beets and small grain do best when they are sown after potatoes grown on alfalfa sod, and that corn does not do well when planted after sugar beets. Under similar conditions in the Yellow-

[6] Rhode Island Agricultural Experiment Station publications: Bulletins 175, 176, 190, and 198.

stone Valley, Mont., it has been found that sugar beets do best when they follow flax in a six-year rotation of alfalfa (three years), corn, flax, and sugar beets; and that in Nebraska, corn will not do best if planted after sugar beets. Many farmers have also learned by experience that corn yields poorly after beets.

The foregoing results serve to emphasize the importance of the right combination and sequence of crops in the rotation.

SHORT v. LONG ROTATIONS

Rotations vary as to the number of years which they occupy. Whether or not a short rotation, such as a three-year rotation, is more effective than a long rotation, say a six-year rotation, for example, depends on the following factors: (1) The combination of crops; (2) the order in which the crops are grown; (3) the number of grass or leguminous crops grown in a given period of years; (4) the number of nonleguminous crops grown in succession; and (5) the quantity of organic matter added to the soil during a given period of years.

Ordinarily, the comparative effectiveness of different rotations can be measured only when one, two, or more like crops are grown in the rotations to be compared, and when comparative yields represent the same seasonal effects—the comparative rotation efficiencies being based on the comparable average yields of the like crops, or the crops common to all the rotations. An important factor commonly to be reckoned with is fertilizers—the kind and quantity applied to the crops in common, or applied per acre in a given period of years.

Grass, hay, and legumes may be called the renovating crops of a rotation, because of a combination of several beneficial effects. The growing of such grasses as redtop, timothy, and clover on heavy soils brings about remarkable changes in the workability of such soils, as a result of the organic matter added in the form of profuse and extensive growths of fine roots. Strong taproot grasses, like sweet clover and alfalfa, function not only in puncturing hard and compact subsoils and thereby promoting soil aeration and drainage, but, because of the high nitrogen and low carbohydrate contents of their roots and stubble, they add to the soil readily available nitrogen. The general renovating effects resulting from the growing of the clovers are well known. In fact, this class of legumes has played and is still playing an important rôle in the improvement of the agriculture of the leading nations of the world.

COMMON ERRORS IN ROTATION

Two common mistakes are thoughtlessly made by some farmers, namely, the growing of two or more intertilled crops and of several small-grain crops in succession on the same land. An intertilled crop following a good clover or alfalfa sod is usually excellent, and, because it is so good, the farmer is tempted to grow two or more intertilled crops following the clover or alfalfa crop. Intertillage, or the growing of intertilled crops, has the inevitable effect of causing a most rapid destruction of the soil organic matter. Thus when several intertilled and small-grain crops are grown after a good sod has been turned under, but little or no permanent soil improvement

can, in the long run, be accomplished, particularly if little or no recourse is made to outside sources for organic matter and elements of plant food. As a safe rule, two small-grain crops of the same kind or two intertilled crops should be the maximum number of non-leguminous crops that should be grown in succession, since this will take care of practically all cases where it becomes necessary to grow another intertilled crop after an intertilled crop, or to grow, for example, wheat after wheat, wheat after oats, or oats after barley.

ROTATION AFFORDS OTHER OPPORTUNITIES FOR SOIL IMPROVEMENT

A very important factor in relation to soil fertility and especially in the maintenance of productivity is the soil supply of readily decomposable or active organic matter. An arable soil adequately supplied with active organic matter is usually a productive soil. This points to an important function of crop rotation, namely, aiding in the maintenance of the soil supply of organic matter. Ordinarily, rotation of crops makes it possible for the farmer to accomplish this in different ways: By plowing under good clover or grass sods, by the timely plowing under of weeds in grain-stubble fields, and by the plowing under of second growths of clover or grass, and volunteer growths of rye, wheat, and oats.

In special ways the addition of organic matter to the soil may be accomplished by green manuring. Very often this means the sacrifice of a season's crop; but, in rotation, opportunities are afforded whereby green manuring can be accomplished without the sacrifice of a season's crop. Rye, clover, soy beans, or other legumes may be sown for green manure, in with such crops as corn and potatoes at the last cultivation, or where the season or climate will permit, after the season's crop is harvested. Usually such crops are plowed under in the late fall. Rye, vetch, and clover may be sown after harvest for catch or cover crops, and turned under for green manure in the following spring. When two small-grain crops are to be grown in succession, clover may be seeded in the first crop, say wheat or oats, and turned under in the fall to benefit the wheat crop which usually follows (fig. 13).

When the soil is in a low or medium state of productivity, mammoth clover may prove best for this purpose, being a more rank grower than the other clovers.

INCREASED EFFECTIVENESS OF CULTIVATION, ROTATION, AND USE OF FERTILIZERS

Since permanent soil productivity depends largely on cultivation of the soil, rotation of crops, and the use of fertilizers, it logically follows that, assuming the use of good seed, soil productivity in general may be materially increased by improved methods of tillage, by improved and more systematic rotation of crops, and by the intelligent use of farm manure, commercial fertilizers, and agricultural lime. Whatever efforts a farmer may put forth in maintaining or in increasing soil productivity by the methods suggested in this bulletin, he should at all times be mindful of these two encouraging facts: (1) Crop rotation may prove as effective as the use of farm manure or commercial fertilizers in maintaining or increasing crop yields; (2) when rotation and the use of fertilizers are conjoined their combined effects on crop yields are additive.

Since the ordinary effects of rotation and of the use of fertilizers when practiced together are additive, it logically follows that when a farmer increases the productive efficiency of his rotations and of the use of fertilizers the increased efficiencies of these two practices, when conjoined, will likewise be additive, and will be thus reflected in increased crop yields.

CROP ROTATION THE STARTING POINT IN BUSINESS FARMING

Although in this bulletin the statement is made that crop rotation of some description is practiced by most of the farmers of the country, even though the rotations may consist in merely a change

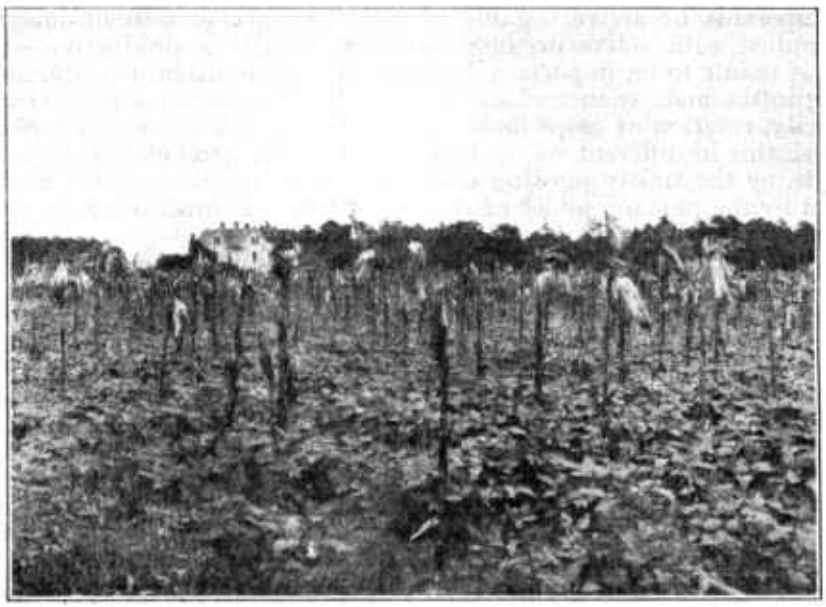

FIG. 13.—Corn and cowpeas after early potatoes (three crops in one growing season), Accomac County, Eastern Shore, Va. The cowpeas are usually plowed under in the fall for green manure. This illustrates how, by means of rotation, a farmer can gather in at least one crop a year and at the same time improve his soils in a way other than by the use of farm manure or commercial fertilizers

in cropping without any definite system or any degree of regularity, yet in some sections farmers have not yet come to know the economic importance of crop rotation because of the want of diversification in farming. From a general-welfare or economic point of view it is generally conceded that, in most of these sections or localities, diversification, wherever it is possible, is the first important step toward more stabilized agriculture, and this stabilization in turn would lead to more contented farm homes, the only conditions which should prevail generally in order that agriculture may be made a strong national bulwark. Diversification in farming is the mother of crop rotation; and rotation is not only a major factor in the maintenance of soil productivity, but the establishment of systematic cropping systems or of proper rotations is the real beginning of organized or business farming.